NREL
National Renewable Energy Laboratory

Enzyme Sugar-Ethanol Platform
Stage 3 Plan

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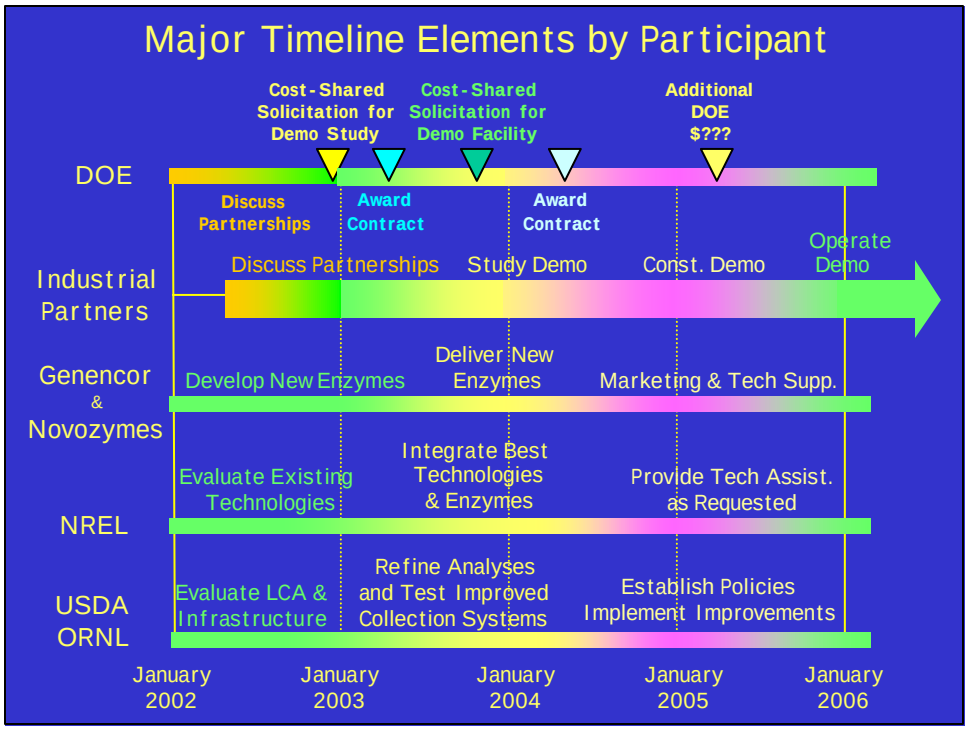
Gate 3 Project Review, Golden, Colorado

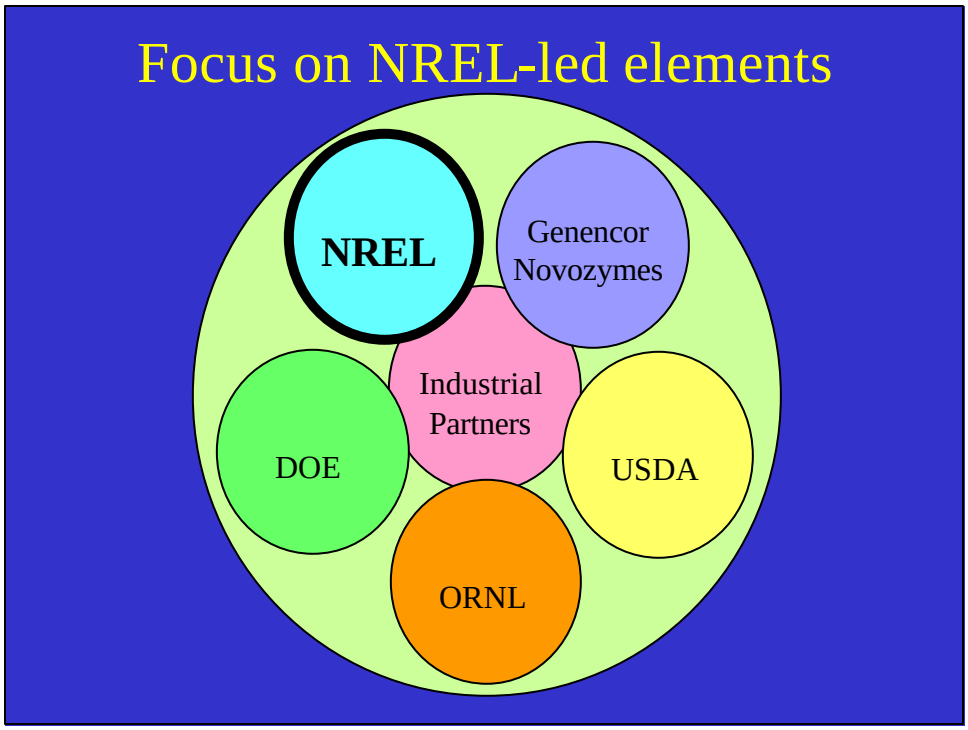
January 31, 2002

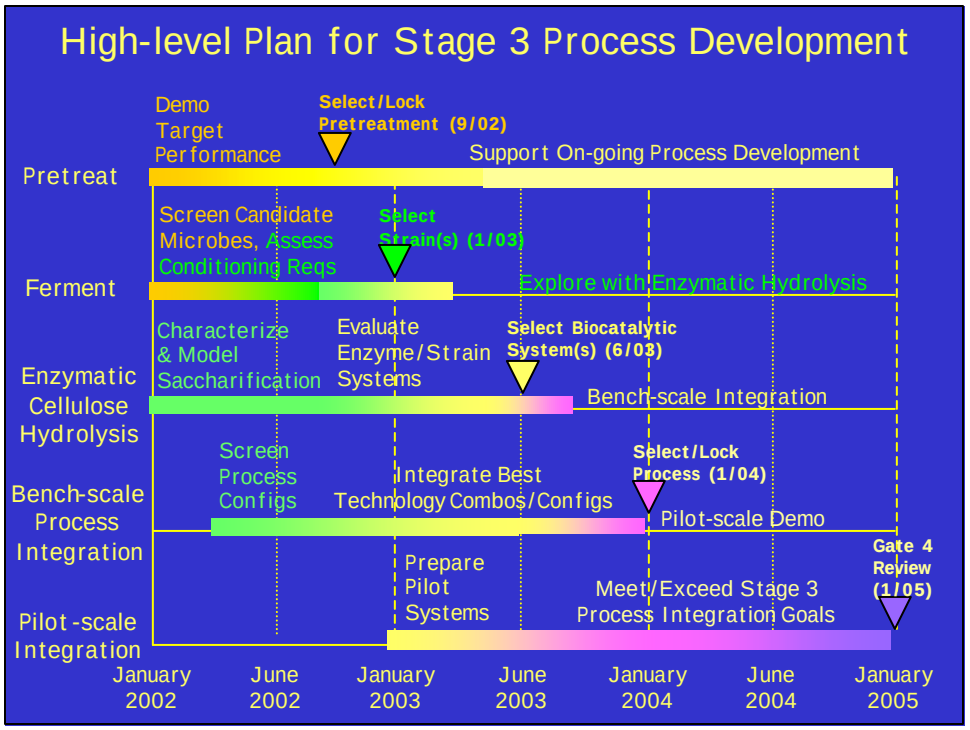
Operated for the U.S. Department of Energy by Midwest Research Institute • Battelle • Bechtel

Stage 3 Plan Overview

- Multi-year phased approach with heavy industry involvement and guidance
  - Anticipate 3-4 year timeframe
- Extend analysis work initiated in Stage 2
  - Market assessment
  - Technoeconomic/financial assessments
  - Life cycle analysis
- Experimentally test or screen selected technology options and initiate integrated process development
  - Feedstock and process sample analysis
  - Pretreatment, enzymatic hydrolysis, and fermentation


Major Timeline Elements by Participant
Cost-Shared Solicitation for Demo Study
Cost-Shared Solicitation for Demo Facility
Additional DOE $???
DOE
Discuss Partnerships
Award Contract
Award Contract
Industrial Partners
Discuss Partnerships
Study Demo
Const. Demo
Operate Demo
Genencor & Novozymes
Develop New Enzymes
Deliver New Enzymes
Marketing & Tech Supp.
NREL
Evaluate Existing Technologies
Integrate Best Technologies & Enzymes
Provide Tech Assist. as Requested
USDA ORNL
Evaluate LCA & Infrastructure
Refine Analyses and Test Improved Collection Systems
Establish Policies Implement Improvements
January 2002
January 2003
January 2004
January 2005
January 2006


Focus on NREL-led elements
NREL
Genencor Novozymes
Industrial Partners
DOE
USDA
ORNL



Outline

- **Project Resources**
- Stage 3 market, financial and LCA assessments
- Stage 3 process development
  - Key Objectives by Area
    - Feedstock/compositional analysis
    - Pretreatment
    - Enzyme
    - Fermentation Microorganism
    - Process Integration
- FY02 Milestones
- Participant roles and responsibilities (RACI)
- Conclusions

FY02 Financial Resources

- Budget: Still being finalized!
- Guidance: ~$2.5 million total, ~9 FTE
- Breakdown:
  - Labor ~$2.0 million
  - ODC: ~ $200K
  - Subcontracts: ~$300K
- The fiscal year is already 1/3 over

FY02 Human Resources

- FTE breakdown (plan)

0.50	Assess market, identify partner
1.50	TEA (process engineering)
0.25	Life cycle analysis
1.00	Feedstock compositional analysis
2.25	Pretreatment
1.50	Enzyme testing and kinetic modeling
1.50	Fermentation strain evaluation
0.25	Explore process integration
0.25	Produce residues and intermediates
9.00	

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Market Analysis

- Increase depth and breadth of previous analyses to better understand market opportunities
  - Collectable amount of corn stover available based on LCA results
  - Ethanol value as gasoline blend stock (demand curve)
  - Impact of starch ethanol production expansion on corn, DDGS, and corn fiber prices
- Assess market risk by extending the analysis of different policy scenarios, including
  - MTBE phase out
  - RFG and oxy-fuel requirements
  - Renewable Fuels Standard
  - Other policy drivers

Technoeconomic Analysis

- With guidance from industry, refine conceptual process model and extend exploration and identification of attractive business scenarios
  - Which scenarios should we go further with?
  - What other scenarios should we evaluate?
- Extend process simulation capabilities to permit more rigorous multi-parameter sensitivities
  - Essential to provide direction to integrated process development
  - Enable “what if” analysis on impact of prospective co-products (biorefinery modeling)

Life Cycle Analysis

- Better understand soil sustainability
  - Continue LCA work to better understand the impact on corn stover removal on land use, soil health, greenhouse gas emissions, and water quality
- Level of funding unclear
  - Relatively small effort at NREL (~0.25 FTE)

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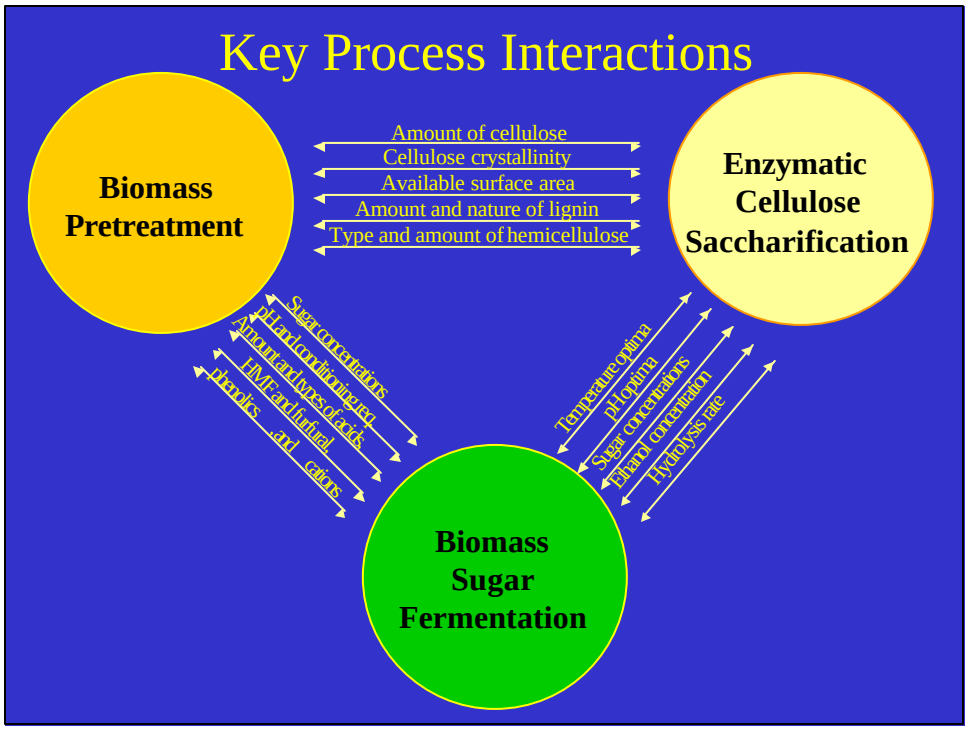
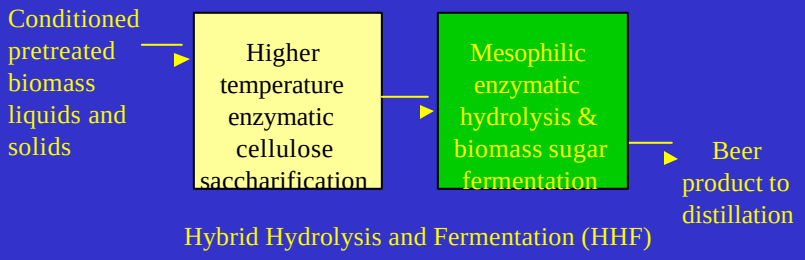
Process Development Objectives

- Identify and understand key process interactions
- Evaluate strengths and weaknesses of top process configuration options identified through process modeling financial assessments
  - Down selecting to identify which to take forward will be guided by industry
- Demonstrate technical feasibility of integrated process performance targets
- Produce process samples for stakeholder and third party evaluation to assess potential co-product value



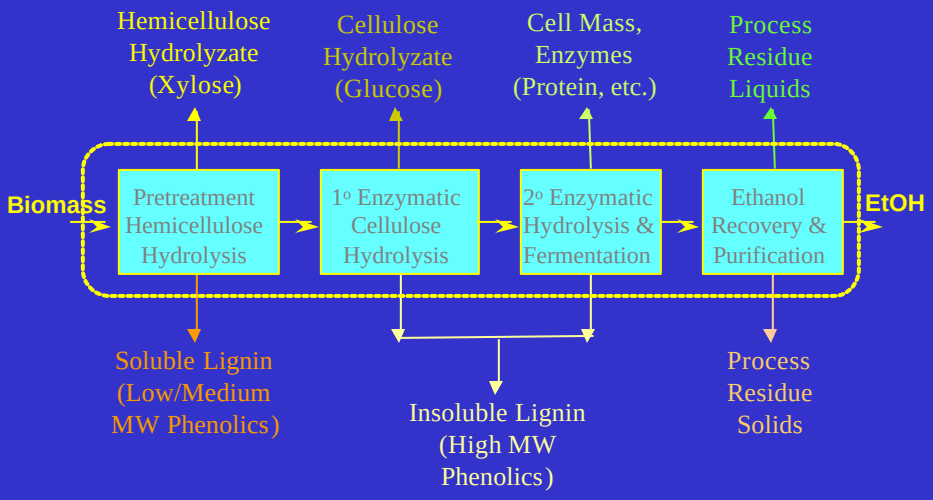
Initial Focus is Hybrid Configuration

- Anticipate using a hybrid hydrolysis and fermentation (HHF) process configuration that begins like SHF and ends like SSF.



Hybrid Hydrolysis and Fermentation (HHF)

Potential Process Co-products



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Feedstock/Compositional Analysis

- Better understand feedstock composition
  - Extend existing methods to enable trace components not currently tracked to be quantified (e.g., uronic acids)
  - Improve existing methods for protein and lignin
  - Continue efforts to measure compositional changes during storage, particularly mass shrinkage
- Better understand pretreatment hydrolyzate composition
  - Extend existing methods to enable trace components not currently tracked to be quantified (solubilized lignin species, hydrolysis limit products, etc.)
  - Elucidate overliming detoxification mechanism

Compositional Analysis, cont'd.

- Leverage off Rapid Analysis project work to refine and develop methods facilitating more efficient process development
  - Improve robustness of near infrared spectroscopy-based rapid analysis methods for analysis of raw, pretreated, and converted corn stover solids
- Incorporate FTIR methods if progress permits:
  - Rapid analysis methods for hydrolyzate liquors
  - In-situ pretreatment monitoring

Pretreatment

- Verify technical feasibility of operating at 30% solids and achieving performance yields targets
  - 85% hemicellulose sugar yields
  - 90% cellulose digestibility
- Produce pretreated corn stover
  - Supply stakeholders, as requested
  - Enable NIR calibration development
  - Enable enzyme and strain evaluations
  - Enable process integration work
- Re-assess economics and readiness of alternative pretreatment as new data becomes available.economics

Enzymes

- Work closely with Genencor and Novozymes to understand the probable characteristics of the next generation enzymes they are developing
  - This will help to guide process development, especially related to strains
- Test interim/new enzymes when they're available
  - Develop kinetic model of stand alone enzymatic cellulose saccharification to facilitate *in silico* optimization
  - Measure model parameters for new enzyme preparations as they become available
- Demonstrate efficacy of final enzymes in extended pilot scale operation using economical loadings

Fermentation Strains

- Screen candidate strains on pure sugars
  - Confirm performance attributes
  - Better understand sugar utilization patterns and rates
- Continue screening on corn stover hydrolyzates
  - Characterize hydrolyzate conditioning requirements
  - Confirm ability to use low cost nutrient sources
- Carry top strains into extended studies
  - Develop/demonstrate low-cost media
  - Explore/optimize process configuration
  - Demonstrate integrated performance (HHF or other)

Process Integration

- Initiate in 2nd year of Stage 3 after options narrowed
  - Pretreat at pilot scale to produce industrially representative material (i.e., high solids pretreatment)
  - Initially work on biologically-mediated steps at bench scale, moving to pilot scale with front-runner options
- Pretreatment/Fermentation
  - Explore real time processing (hydrolyzate stability)
    - Pretreat ✍ Condition ✍ Ferment
- Saccharification/Fermentation
  - Explore integration of top strains with available cellulases
- Pretreatment/Saccharification/Fermentation
  - Top options only

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FY02 Milestones

- Commercialization Path, Market & Financial Assessment
  - Strategy for industrial involvement (C, 4/02)
  - Assess market and pricing for corn-based ethanol during the period 2002 – 2010 (P, 7/02)
  - Establish combustion characteristics of process residue (S, 9/02)
- Feedstock
  - Updated NIR model for raw corn stover feedstock (S, 2/02)
  - Updated corn stover standard analytical protocols (LAPs) (P, 3/02)
  - Status report on corn stover-to-ethanol LCA modeling (P, 5/02)
  - Causative factors for compositional variability (C, 7/02)
  - Report on compositional stability (P, 8/02)

FY02 Milestones, cont'd.

- Pretreatment
  - Updated NIR model for stover process intermediate solids (S, 12/01)
  - Confirm pretreatment system readiness (P, 2/02)
  - Characterize pretreatment response surface (C, 9/02)
- Enzymatic Hydrolysis
  - Kinetic model for enzymatic saccharification (C, 4/02)
- Fermentation
  - Down select strains for further testing (P, 9/02)

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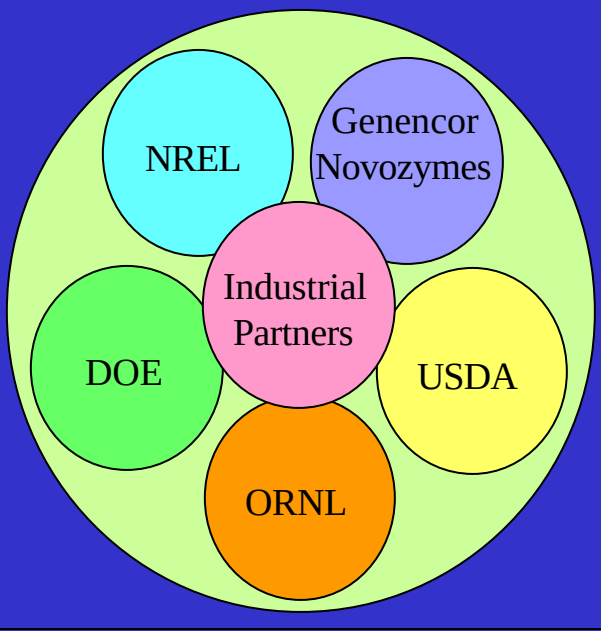
Stage 3 Project Team



Proposed Stage 3 Project RACI*

	Core Project Participants								Other NREL Biofuels Projects					
Major Tasks	DOE EERE/OFD	DOE GO	NREL	ORNL	USDA ARS	USDA NRCS	Genencor & Novozymes	B/MAP	Industrial Partners	Rapid Analysis	Advanced Pretreatment	Strain Fundamentals	Enzyme Fundamentals	Industrial Partnerships
Supply feedstock	I		R					A/R			I			
Integrate technology	I		A/R						R					
Produce/distribute process intermediates	I		A/R	C	C	C	C		C	C		C	C	
Feedstock harvesting/handling	C	C	I	A/R	R	R		C	I					
Soil health and sustainability	C	C	I	C	A/R	R			I					
Life cycle analysis	C		A/R	R	R	R	C	C	C					C
Enzyme development	I		C				A/R		I				R	
Select industrial partner(s)	A/R		C						I					R

*RACI: R = Responsible; A = Accountable; C = Consult; I = Inform

Unresolved Issues

- Coordination and ownership of tasks by all project participants is critical to success.
  - Need confirmation that USDA and ORNL accept and can execute the tasks proposed in the project RACI
  - High-level ownership of this project outside of DOE OFD and NREL doesn't yet exist but is critical to success
- Need to better understand what the actual enzyme costs will be ($/gallon EtOH) after 10x cost improvement to better understand process economics
  - Compelling scenarios must be based on actual not assumed enzyme costs. Process performance data is needed.

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✍ **Conclusions**

Conclusions

- Probably of success difficult to gauge, despite apparent technical feasibility of conversion process proper
  - Ownership and funding uncertain for key feedstock infrastructure and collection cost issues
  - Actual cost of final enzymes remains unknown
- Overall Stage 3 plan developed
  - Aggressive timeline and project plan
    - Detailed demo plant design probably needs to be pushed back one year so process better defined
    - Process integration progress requires effectively down selecting among many process options to a manageable few (keep work scope within resource constraints)

Questions?

Comments?

Suggestions?

THANKS AGAIN FOR ATTENDING!

WE APPRECIATE YOUR PARTICIPATION!